

Influence of Rogue Droplet
Atomization on Incineration Effectiveness

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INFLUENCE OF ROGUE DROPLET ATOMIZATION ON INCINERATION EFFECTIVENESS

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ABSTRACT

Large, errant droplets exist in all practical fuel sprays where mechanical atomization is used to disperse the liquid fuel jet. In liquid hazardous waste incineration, the ballistics of these rogue droplets can limit destruction efficiency. To better understand the influence of rogue droplet atomization on incineration effectiveness, the trajectories and carbon destruction efficiency of fuel oil droplets were measured in a 100 kW combustor. The single, monodisperse droplet streams were injected into swirling, turbulent gas flames with parametric variation in initial droplet size, velocity, spacing, and injection angle. Using a three-dimensional algorithm for modeling drag during the initial heating and evaporation of an isolated burning droplet, predictions of droplet trajectories are compared with experimental results. Further development of the droplet ballistics model to explore the effects of droplet interactions and gas flowfield turbulence is ongoing. The correlation of droplet penetration with droplet incineration suggests that incinerator failure modes may be predicted on the basis of droplet atomization parameters and flame flowfield conditions.

INTRODUCTION

With landfill disposal of hazardous wastes becoming increasingly unacceptable due to growing public concern and increased hazardous waste production, thermal destruction of the organic component (a very large fraction) of these wastes is being considered as an alternative disposal method. Successful incineration requires that flame radicals and high temperatures be combined in such a way that the principal organic hazardous components (POHC's) of feed waste are combusted with a 99.99 percent or greater destruction/removal efficiency (DRE). Further, environmentally safe incineration requires that products of incomplete combustion (PIC's), which may be as hazardous as or even more hazardous than the original POHC's, must be minimized. Because the consequences of incomplete incineration to a locality's environment and health are so great, prediction of incinerator effectiveness is essential prior to implementation.

Of the hazardous organic wastes produced in the U.S., about 75 percent are liquids or dissolved in liquids. In liquid spray combustion, the physical processes of atomization and droplet aerodynamics and the thermal and chemical processes of thermodynamics, heat transfer, and kinetics are coupled, resulting in a complex set of governing equations for droplet motion and incineration. The combustion of liquid fuels in most practical swirled combustors is

dominated largely by the overall dynamics of the fuel spray and by the combustion of particle clouds, rather than by the trajectories of single droplets.¹ Semi-empirical solutions have been derived for both single droplet and group combustion by assuming simplified (external) fluid mechanics and mean droplet properties.²⁻⁴ However, these models are inadequate in predicting critical pollutant emissions from liquid hazardous waste incinerators.

In the incineration of liquid hazardous wastes, the penetration or bypassing of the flame zone by a very few individual droplets can lead to a failure mode. For example, the escape of one 200 μm droplet out of 10 million droplets, with a mean diameter of 20 μm , will lead to a DRE of less than 99.99 percent and, thus, to failure of the incinerator. Measurements of droplet size distributions in various fuel sprays have shown that droplets are present with diameters of 200 μm and more, an order of magnitude larger than the mean.⁵ These droplets tend to concentrate at the outer edge of the spray core, with trajectories dominated by their own large momentums. The subsequent fate of these "rogue" droplets is then of paramount importance.

A study was begun at the U. S. Environmental Protection Agency (EPA) to measure and predict the trajectories of single, monodisperse droplet streams in turbulent, swirling combustion flowfields as a function of the droplet atomization parameters of size, velocity, spacing, and angle. It has been found that physical processes can dominate chemical kinetic effects during large droplet combustion, resulting in droplet penetration of the flame zone.^{6,7} To predict these results, a general three-dimensional algorithm for modeling drag during the initial heating and evaporation of an isolated burning droplet was used. The ongoing research at EPA focuses on the development of this model to include the effects of multiple droplet interactions and flowfield turbulence. Further, data are presented here that show a correlation of droplet trajectory with droplet incineration. Thus, rogue droplet atomization may be a useful predictor of incinerator failure.

ISOLATED DROPLET BALLISTICS MODEL

A simple, numerical model has been developed for predicting the ballistics of an isolated burning droplet.⁸ The model is used to solve the uncoupled equations of droplet motion in a Lagrangian framework. A three-dimensional grid structure is established for specifying the (experimentally measured) mean background gas velocity, temperature, and chemical speciation. A single stream of spherical, homogeneous droplets enter the computational domain at a specified position with specified (experimentally measured) initial values for droplet diameter, spacing, temperature, and velocity. The process is modeled in two steps: droplet heating to the liquid boiling point, followed by droplet evaporation. Calculations are terminated when the droplet exits the computational domain. Drag, calculated using an empirical coefficient suggested by Lambiris and Combs⁹, and gravitational forces are assumed to be the only external forces on the droplet.

During droplet heating to the liquid boiling point, its diameter is assumed to be constant (i.e., no evaporation). Here, the time rate of change of the droplet temperature is given by

$$\frac{dT}{dt} = 6 \frac{Nu \lambda_g}{D^2 c_{p_l} \rho_l} (T_\infty - T) \quad (1)$$

where T is the droplet temperature, T_∞ is the combustion gas temperature, D is the droplet diameter, t is the time, Nu is the Nusselt number, λ_g is the thermal conductivity of the combustion gas, c_{p_l} is the specific heat capacity at constant pressure of the liquid droplet, and ρ_l is the liquid droplet density.

The Nusselt number is calculated using an empirical relation. After the droplet temperature reaches the boiling point, evaporation begins. In this stage of pre-ignition, the time rate of change of the droplet diameter is given by

$$\frac{dD}{dt} = -C_B \frac{1}{2D} (1 + 0.23 Re^{0.5}), \quad (2)$$

where C_B is the evaporation constant, which depends on local gas properties, and Re is the Reynolds number.

EXPERIMENT

The objectives of this ongoing study are (1) to measure and predict the three-dimensional trajectories of single monodisperse droplet streams in turbulent, swirled combustion flowfields, and (2) to study the correlation of these trajectories with droplet incineration effectiveness.

Apparatus and Methods

The bench-scale combustion facility is shown in Fig. 1. The 100 kW combustor is a horizontal cylinder with a large quartz window for flame visualization and multiple ports for in-flame sampling. A movable-block swirl burner¹⁰ with interchangeable fuel nozzles is mounted on the combustor and is capable of providing near-burner zone aerodynamic simulation of various flame types. The front wall contains a slot to allow for off-axis droplet injection. A movable cooling coil for quenching the post-flame gases is shown.

Natural gas was burned with an excess air level of 30 percent, ensuring that sufficient oxygen was available for droplet combustion. Two flame shapes with very different mixing patterns have been established: Type C and Type A.¹¹ The Type C flame, produced with a high combustion air swirl (swirl number=1.3) and a 45 degree fuel jet nozzle, is 10 to 15 cm long and is stabilized on the burner quarl by strong primary internal recirculation of the hot combustion gases. The Type A flame, produced with a minimum combustion air swirl for

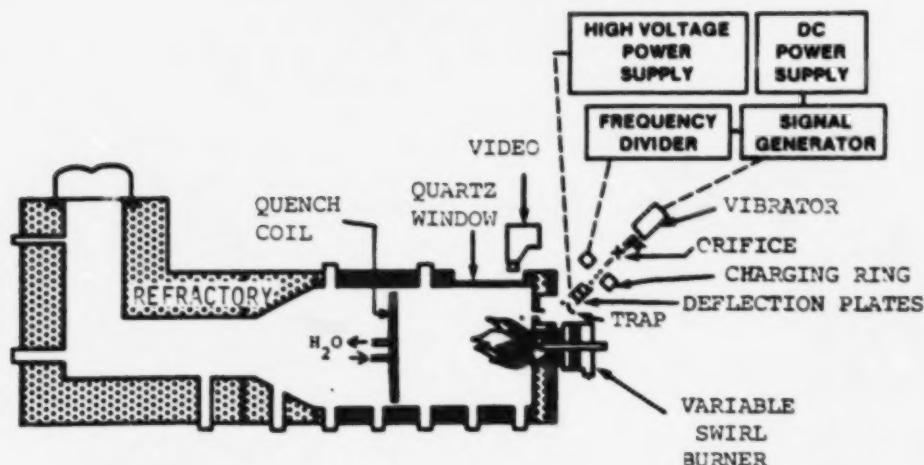


Figure 1. Schematic of bench-scale combustion facility. The 50 cm internal diameter, 90 cm long near-burner combustion module is water-cooled and insulated with a 4 cm thick refractory lining. The IFRF burner has a movable-block air swirl generator and interchangeable fuel nozzles. The monodisperse droplet generator is shown with electronics for droplet separation. The water-cooled coil is shown in the combustor for quenching the combustion gases.

flame stabilization (swirl number=0.65) and axial fuel injection, is 50 to 60 cm long. The Type C flame is most typical of practical, high efficiency combustion systems; therefore, this flame type was used for the nominal test condition.

The droplet generator is a vibrating orifice device with ancillary electronics to facilitate droplet spacing variation.¹² The longitudinally vibrating orifice, driven by a signal generator at 12 to 15 kHz, reinforces the natural Rayleigh instability of the liquid jet, thereby producing a monodisperse stream of droplets without satellites. Droplet injection parameters varied are spacing, size, velocity, and angle. To vary droplet spacing, every Nth droplet is charged by a pulsing charging ring and then deflected by high voltage deflection plates. The neutral droplets are trapped and recirculated, while the charged droplets enter the combustor. Thus, initial droplet spacing, L^0 , is varied by adjusting the frequency divider setting, N, controlling the charging ring. Initial droplet diameter, D^0 , is varied by changing orifice sizes, with the diameter found to be approximately twice the orifice diameter. Initial droplet velocity, V^0 , is varied by adjusting the liquid supply pressure and, hence, the liquid flow rate. Droplet spacing is varied independent of other variables, whereas droplet size and velocity variations are not independent. The droplet generator assembly is mounted on a swivel fixture which permits a variation in the angle of droplet injection at a distance of approximately 14 cm from the burner axis.

Droplet diameter and droplet spacing in the uncharged stream, L_s , are measured directly using a stroboscope to illuminate and freeze droplet images under a microscope at the location of initial droplet separation (the center of the deflection plates). The initial droplet spacing after separation is given by the relation

$$L^0 = L_s \times N \quad (3)$$

Initial droplet velocity is given by

$$V^0 = L_s \times f \quad (4)$$

where f is the vibrator frequency. One droplet is produced with each vibration. An independent measurement of liquid flow rate provides a mass balance check.

The trajectory starting point is defined as the droplet entry location to the combustor, 10 cm downstream of the center of the deflection plates. Therefore, to define the initial droplet velocity and spacing at the trajectory starting point, a two-dimensional cold flow model is used. This model, discussed later in this paper, determines how much the droplet has slowed down due to drag and gravity forces prior to entering the combustor. For a nonevaporation droplet, droplet spacing is related to droplet velocity by $L/V = \text{constant}$.

Radial profiles of temperature, velocity (three components), and species were measured at several radial and axial positions. Gas temperatures are measured by suction pyrometry; axial, radial, and tangential velocity components are measured by using a calibrated five-hole pitot probe (watercooled with 0.8 cm uncooled tip). "Instantaneous" velocities of the turbulent flow are recorded, allowing means and standard deviations to be calculated with a microcomputer. Radial profiles of axial velocity are consistent with overall mass balance.

The fluid that has been tested, chosen on the basis of conductivity (for electrostatic charging and deflection) and viscosity (for droplet formation), is a mixture of 80 percent (by volume) Shell Oil Company fuel additive ASA-3, comprised mostly of xylene (C_8H_{10}), and 20 percent distillate fuel oil. Droplet trajectories were measured and recorded manually, with the aid of high speed photography. Hydrocarbon destruction efficiency is determined by measuring the increase in exhaust unburned hydrocarbons (surrogate POHC), UHC, and carbon monoxide (PIC), CO, with droplet injection over the levels without droplet injection. These emission measurements were taken from the stack where the combustion gases are well mixed. Flame ionization is used to detect UHC, and an infrared instrument is used for CO measurement. A removable water-cooled coil for quenching the combustion gases is located nominally at 41 cm into the furnace, well downstream of the Type C flame. This results in a bulk gas residence time of 0.6 seconds before quenching. The quench coil provides a means of adjusting the effective refractory wall volume to simulate actual droplet post-flame residence times before cold wall impingement.

Approach

Baseline measurements (i.e., no droplet injection) of combustion gas temperature and velocity were measured first. The quench coil was completely removed from the combustor for these measurements. Then droplet trajectories were observed for a variety of initial droplet stream conditions, including variation in droplet size, velocity, spacing, and injection angle. These measurements were also taken without the quench coil inserted. Model development ensued, with droplet interactions and turbulence effects being considered. Finally, droplet incineration measurements were made with the quench coil located at 41 cm.

DROPLET TRAJECTORY RESULTS

In the cylindrical polar coordinate system used, x is the axial coordinate, r is the radial coordinate, and θ is the angular coordinate, defined as zero in the horizontal plane and 90 degrees at the top of the combustor.

Type C Flame Characterization

A peak flame temperature of 1750 K was measured at the combustor centerline, near the tip of the visible flame, with temperatures decreasing to approximately 1100 K at the wall (Fig. 2). Axial symmetry was observed.

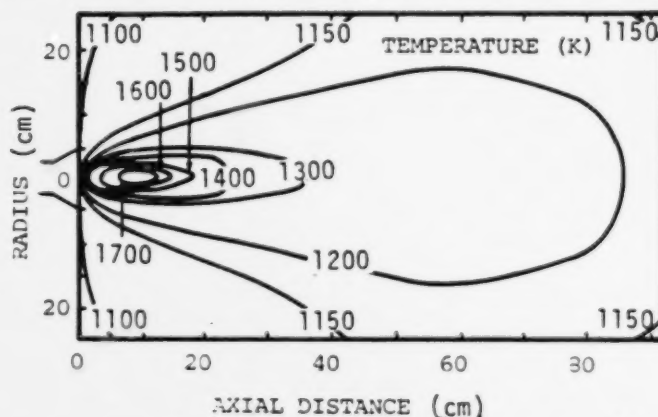


Figure 2. Near-burner zone isotherms for Type C flame baseline. This thermal map is constructed from axial and radial temperature profiles. Symmetry about the centerline axis was verified with a limited number of measurements and is assumed for the entire field.

Figure 3 exhibits maps of the mean axial, radial, and tangential velocity components in the near-burner zone. At each point there is actually a distribution of velocities over time due to turbulent fluctuations in the reacting flow. Standard deviations of velocity were in the range of 1 to 5 m/s, often exceeding 50 percent of the mean velocity. The axial velocity map shows strong internal recirculation within the flame (indicated by negative velocities), as well as external recirculation near the combustor walls. Peak

velocities of greater than 25 m/s were measured near the burner quart exit, consistent with the input air velocity at the burner throat of 28 m/s. The calculated bulk mean axial velocity, approximately 2.6 m/s, is approached beyond the 50 cm axial distance.

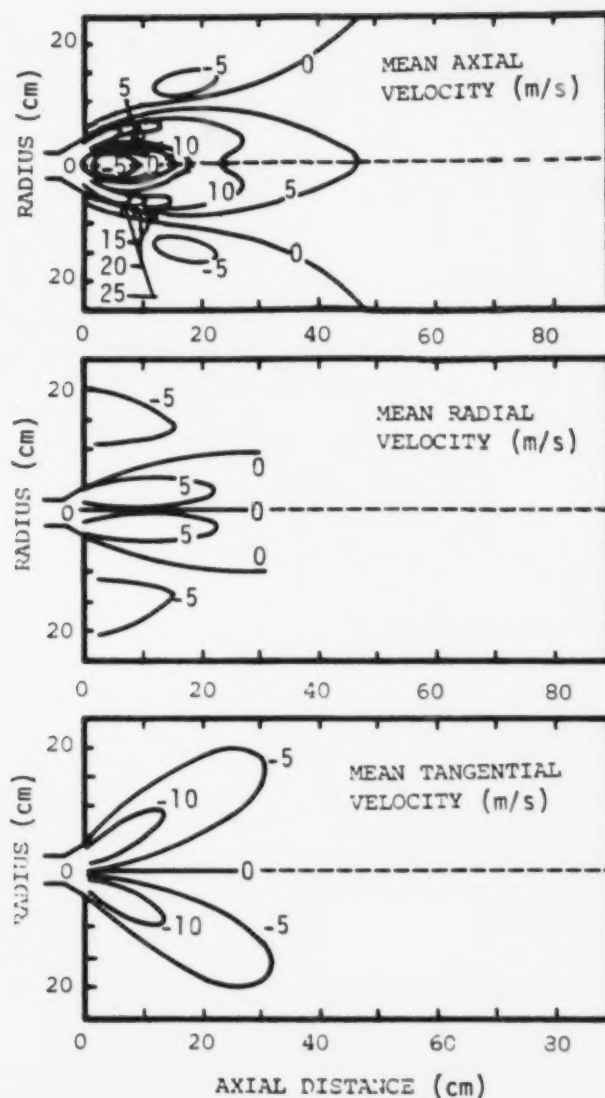


Figure 3. Near-burner field velocity maps for Type C flame baseline. The lines of constant velocity are constructed from three-dimensional axial and radial velocity profiles. Symmetry about the centerline axis was verified and is assumed for the entire field.

Mean radial velocities were found never to exceed 8 m/s. Very little radial motion of the combustion gases was seen beyond the 25 cm axial location. Mean tangential velocities were found to be negative, consistent with the direction of swirl. A strong degree of swirl was observed near the burner quarl exit, with the swirl mostly dissipated by 40 cm downstream. The peak tangential velocity of approximately 12 m/s is consistent with a swirl number of 1.3.

Droplet Trajectory Measurements

Fourteen test conditions were evaluated, with droplet trajectories measured for variations in droplet spacing, velocity, size, and injection angle (Table 1).

TABLE 1. DROPLET INJECTION CONDITIONS AND MEAN AXIAL PENETRATION

<u>Test Variable</u>	<u>Test Variable Value</u>	<u>Mean Axial Penetration, cm</u>	<u>Model Prediction, cm</u>
Nominal	---	30	23
Size, μm (D°)	297	45	33
	378	55	50
Velocity, m/s (V°)	3.8	20	18
	9.8	45	25
Spacing (L°/D°)	2.5	55	*
	4.7	45	*
	8.8	35	*
	16.7	30	*
	32.3	30	*
Angle, deg. (θ)	0	30	18
	45	35	28
Flame Type	A	25	*

The domain of droplet trajectories observed for the nominal test condition is shown (Fig. 4) in the two planes of observation. Superimposed on the cross-sectional view along the centerline axis are lines of constant mean axial velocity of the combustion gases. The droplets were observed to follow an approximately common path until they entered the high shear layer of the combustion gas. The burning times were very short, as indicated by the burning droplet "flecks" stretching only a few centimeters. The large shaded area denotes the distribution of burning droplets, igniting and burning out at various locations in this area. Thus, no single trajectory describes the test condition. The existence of a domain of droplet stream burnout locations, rather than a single burnout point, suggests that either the droplet injection properties are nonuniform or the gas flowfield fluctuates with time (i.e., turbulence). Uniformity of droplet formation and injection was carefully monitored during testing. Therefore, the range of trajectories observed in the experiment is attributed to high combustion gas turbulence. The large velocity fluctuations that were measured support this hypothesis.

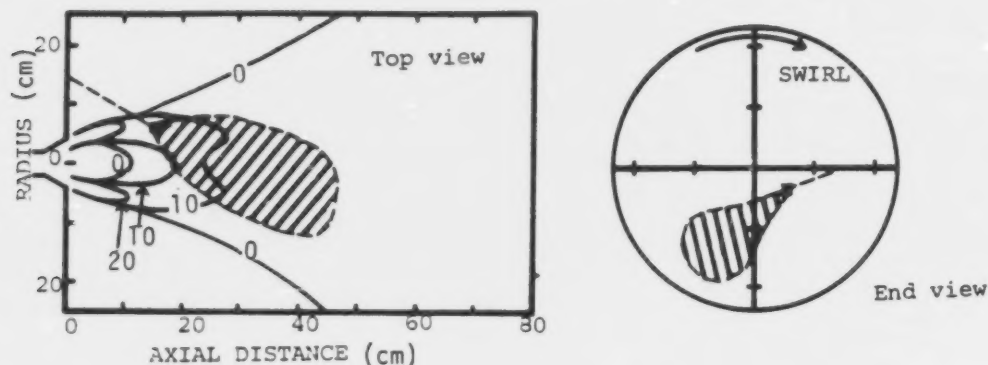


Figure 4. Droplet trajectory for the nominal test condition. The domain of droplet burnout locations is shown by the shaded area. An axial velocity profile is superimposed in the top view drawing.

Measured mean axial droplet penetration distances are listed in Table 1. Closely spaced droplets penetrate farther than isolated droplets. Little effect of spacing was observed for values of greater than 20 diameters. Axial penetration roughly doubles for a doubling of initial droplet velocity. Axial penetration increases as droplet diameter increases, as well. The effect of injection angle was observed for both the isolated droplet and the droplet stream. Little change in axial penetration distance was observed either for isolated droplet injection at 0, 30, and 45 degrees or for droplet stream injection at 0 and 30 degrees. Finally, a change in the combustion gas flowfield from a Type C to a Type A flame resulted in a slight reduction in the penetration of the droplet.

Model Development

The isolated burning droplet ballistics model was run, with Type C flame baseline data and droplet injection parameters as model inputs. The predicted axial location at which the droplet is completely evaporated is compared to the measured mean axial penetration (Table 1). While the predicted radial and circumferential distances travelled before complete droplet evaporation closely agree with experimental results, the model predictions are all less than the axial penetrations observed in the experiment. However, predicted trends match those measured experimentally for droplet injection size, velocity, and angle.

To better predict the experimental results two areas of model development have been identified. First, droplet spacing effects must be modeled in terms of drag and burning rate influences. Second, gas flowfield turbulence effects must be modeled to predict the distribution of trajectories observed (Fig. 4).

Droplet Interactions. Two additional experiments were performed to evaluate droplet spacing effects on droplet trajectories. To better understand droplet spacing effects on aerodynamic drag, the trajectories of single, monodisperse, nonevaporating droplet streams were measured in cold flow tests and predicted with a two-dimensional model. To study droplet spacing effects on droplet burning, droplet stream trajectories were measured in a two-dimensional flat-flame burner environment.

While much data are available on the relationship of the drag coefficient, C_D , of a sphere to Reynolds number, Re , little information is available on the dependence of C_D on droplet spacing. The conventional correlation for the drag on a sphere in steady motion is typically presented as a graph called the "standard drag curve," where C_D is plotted as a function of Re . Many empirical or semi-empirical equations have been used to approximate this curve. For the slightly distorted droplets formed by a vibrating capillary droplet generator, the relation of Lambiris and Combs⁹ has been recommended:¹³

$$C_{D,L/D \rightarrow \infty} = \begin{cases} 27 Re^{-0.84}, & 0 < Re < 80 \\ 0.271 Re^{0.217}, & 80 \leq Re < 10^4 \\ 2, & Re \geq 10^4 \end{cases} \quad (5)$$

Here, $C_{D,L/D \rightarrow \infty}$ refers to the drag coefficient of an isolated droplet, or to that of a droplet stream as L/D gets very large. In the other extreme, as the droplet spacing approaches the droplet diameter, the drag coefficient is assumed to approach the friction drag coefficient of a long cylinder. Computed from theory, the friction drag coefficient can be approximated by¹⁴

$$C_f = \frac{8}{Re_D \ln[(4L/D)/Re_D]}.$$

For very long cylinders (i.e., $(L/D)/Re_D \geq 10^4$) this expression becomes

$$C_f \leq 0.755/Re_D$$

For the continuous stream surface (i.e., $L/D = 1$) the friction drag coefficient is assumed to be

$$C_f = b \times (0.755/Re_D) \quad (6)$$

where parameter "b" is an empirical correction factor.

Employing the asymptotic values approximation, C_D can be estimated by

$$(C_D)^{-n} = (C_{D,L/D \rightarrow \infty})^{-n} + (C_{D,L/D \rightarrow 1})^{-n} \quad (7)$$

where $C_{D,L/D \rightarrow 1}$ refers to the drag coefficient of the droplet stream as the droplet stream approaches a continuous stream of liquid rather than discrete droplets. It is hypothesized that

$$C_{D,L/D \rightarrow 1} = C_f + aRe^{-1} \ln(L/D) \quad (8)$$

where parameter "a" represents the slope of the line at constant Re of C_D approaching C_f as L/D approaches 1.

Using a two-dimensional cold flow droplet trajectory model and a nonlinear regression routine, best-fit values of "n," "b," and "a" were determined from the experimental data. The results were:

$$\begin{aligned} n &= 5.67 \\ b &= 0.8 \\ a &= 35.4 \end{aligned}$$

Figure 5 shows the predicted trajectories (lines) versus the measured trajectories (points). The model is found to be a statistically effective predictor of cold flow trajectories. Having empirically determined values for "n," "b," and "a," C_D can be evaluated as a function of Re and L/D . This is shown in Fig. 6. At constant Re , as L/D increases, C_D increases from C_f to $C_{D,L/D \rightarrow \infty}$. For low Re , the transition region of the graph is small. However, as Re increases, the critical value of L/D , above which the droplet stream behaves as isolated droplets, increases. This is consistent with an increasing wake length behind a droplet with increasing Re . Thus, the influence of droplet spacing on drag coefficient has been quantified and can be input into the three-dimensional burning droplet ballistics model to predict droplet trajectories in flames. A paper on this work is being prepared for publication.

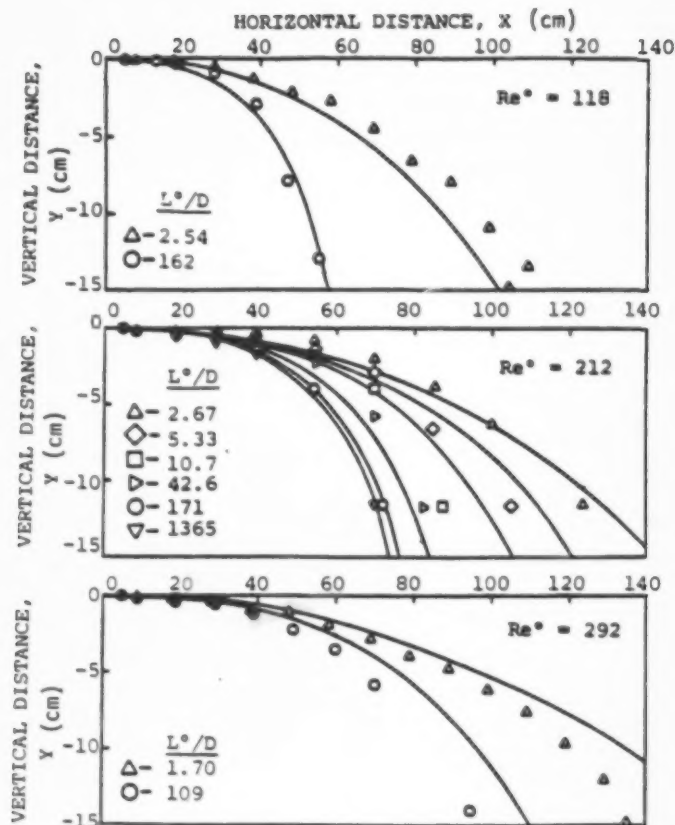


Figure 5. Comparison of measured droplet stream trajectories (points) and model predictions (lines) in cold flow system.

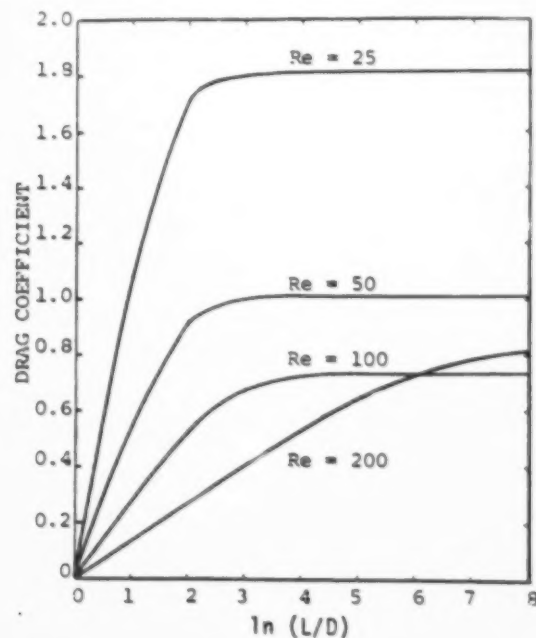


Figure 6. Droplet drag coefficient as a function of Re and L/D .

It is well known that interactions between droplets in spray combustion reduce droplet evaporation rates as compared with the case of the isolated droplet.¹⁵⁻¹⁷ The smaller the interdroplet spacing in a spray, the stronger is the competition for available oxidizer. This droplet interaction has been studied at EPA in a two-dimensional flat-flame burner system where turbulent effects have been eliminated. Combustible and nonburning droplets have been studied to differentiate droplet drag effects from droplet burning effects. Initial droplet spacing (L^0/D^0) was varied from 2 to 1000. The results indicate that droplet interactions can significantly reduce the droplet burning rate, even for large droplet spacings. The model development to incorporate this finding is ongoing and will be reported on at a later date.

Thus, both effects of droplet interactions, decreased droplet drag and burning rate, tend to increase droplet penetration. This was observed in the swirling, turbulent flame tests previously described (Table 1).

Turbulence Effects. The current model does not include turbulence effects and, therefore, does not predict the distribution of trajectories observed in the experiment (Fig. 4). The model is being modified to include the effects of turbulence on droplet dispersion via the stochastic approach proposed by Dukowicz¹⁸ and recommended by Gosman and Ioannides.¹⁹ By this "discrete droplet" method the gas turbulence is randomly sampled during each droplet's flight and allowed to influence its motion. The total stream behavior is obtained by averaging over a large number of droplets. The number of droplet paths simulated is determined statistically, with the number being sufficient to describe a distribution of trajectory endpoints. This modeling is ongoing and will be reported on at a later date.

Preliminary results from this effort are encouraging. Using mean flowfield velocity inputs, the model predicts two phases of droplet ballistics. Initially, during droplet heating to its boiling point, the predicted droplet trajectory is insensitive to combustion gas flowfield velocities. As droplet evaporation occurs, sensitivity to gas velocity increases and the droplet is transported by the mean gas flowfield. With the modified model incorporating flowfield turbulence, this second phase of the droplet trajectory results in a large variation in droplet path endpoints for a given condition. More work is necessary to determine an appropriate turbulence length scale for the system being modeled.

DROPLET INCINERATION RESULTS

The Type C flame droplet trajectory tests were repeated with the quench coil inserted at the 41 cm axial location. This coil reduced the bulk combustion gas temperature by 200 to 300 K, cooling the entire gas flow to less than 1100 K. The gases were well mixed prior to extraction for gas species analysis. The emissions were analyzed without droplet injection (baseline condition), then with droplet injection, and again without droplet injection.

The change in exhaust CO and UHC levels was noted, with hydrocarbon destruction efficiency being calculated based on the mass of carbon emitted as CO and UHC divided by the mass of carbon injected in the droplets. The nominal droplet condition was a 225 μm diameter droplet injected with a 6.5 m/s velocity, with a spacing of 130 droplet diameters, and at an angle of 30° from axial toward the burner centerline.

Results are shown in Fig. 7. The previously measured mean axial penetration is shown, with dotted lines representing the range of droplet trajectories. For the nominal test condition the injected hydrocarbon in the droplet was completely destroyed. However, as initial droplet diameter increased to almost 400 μm , droplet hydrocarbon destruction efficiency decreased to less than 70 percent and the mean axial penetration increased to 55 cm (Fig. 7a). Similarly, as initial droplet velocity increased from 4 to 10 m/s, mean axial penetration increased from 20 to 55 cm and droplet hydrocarbon destruction efficiency decreased from 100 to 80 percent (Fig. 7b). In Fig. 7c, the correlation of mean axial penetration and hydrocarbon destruction efficiency is observed for initial droplet spacing variation. As initial droplet spacing decreases, axial penetration increases and hydrocarbon destruction efficiency decreases. In Fig. 7d, it is shown that droplet injection angle had little effect on either droplet penetration or hydrocarbon destruction efficiency.

The incineration data indicate that droplet hydrocarbon destruction efficiency is related inversely to droplet penetration, which depends on droplet atomization properties. Though uncertainty in the droplet hydrocarbon destruction efficiency is large (about 5 percent) due to the small droplet feed rate relative to the natural gas feed rate, the data indicate that destruction of the hazardous components of rogue droplets may be difficult and that potential incinerator failure modes exist due to incomplete combustion of rogue droplets. Thus, predicting rogue droplet ballistics may be an important tool for anticipating incinerator failure modes due to poor atomization.

CONCLUSION

Large droplet penetration of the flame zone has been observed as a function of droplet atomization parameters in tests with single, monodisperse droplet streams injected into swirling, turbulent flames. The incomplete incineration of these hydrocarbon droplets has been approximated by measuring CO and UHC emissions, and a strong correlation with droplet penetration was observed. The short burning distances and relatively long trajectories prior to ignition exhibited suggest that droplet aerodynamics prior to ignition is of primary importance in understanding and predicting DRE.

Model development of droplet ballistics is ongoing. This development addresses two critical areas: (1) droplet spacing effects and (2) flowfield turbulence effects. Droplet interaction results in both decreased droplet drag and increased droplet burning time, each contributing to greater droplet penetration. Experiments in cold flow and in a flat-flame burner environment have been performed to evaluate these effects. A statistical method of representing turbulence, using measured velocity fluctuations, is being developed.

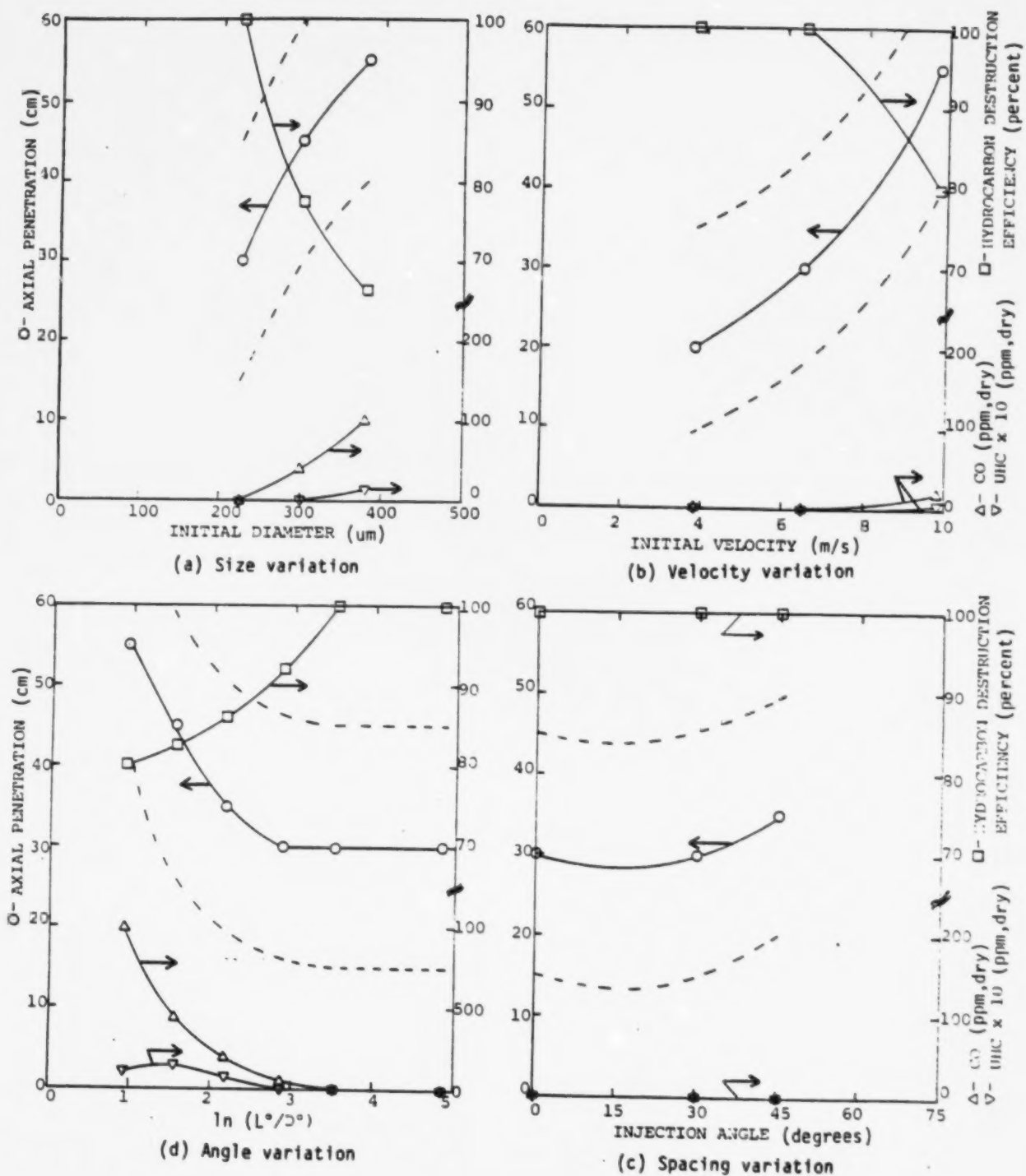


Figure 7. Comparison of droplet mean axial penetration and droplet carbon destruction efficiency.

The correlation of droplet penetration with droplet incineration may allow for the prediction of incinerator failure modes based on droplet atomization parameters.

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